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Attitude Control and Energy Storage Experiments at Glenn Research Center

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Introduction

The ACESE experiment at NASA Glenn Research Center will demonstrate a system with DC bus regulation and single axis momentum control capability

Presentation Topics:

- Research Tasks completed during FY01
  - Field oriented motor control
  - DC bus regulation
  - Magnetic bearing sensor upgrade
  - Magnetic bearing controller development – Talk by Dr. D.K. Le
- Description of ACESE experiment
- Objectives for FY02
- Description of flywheel modules
- Description of High Energy Flywheel Facility
- Summary

Field Oriented Motor Control

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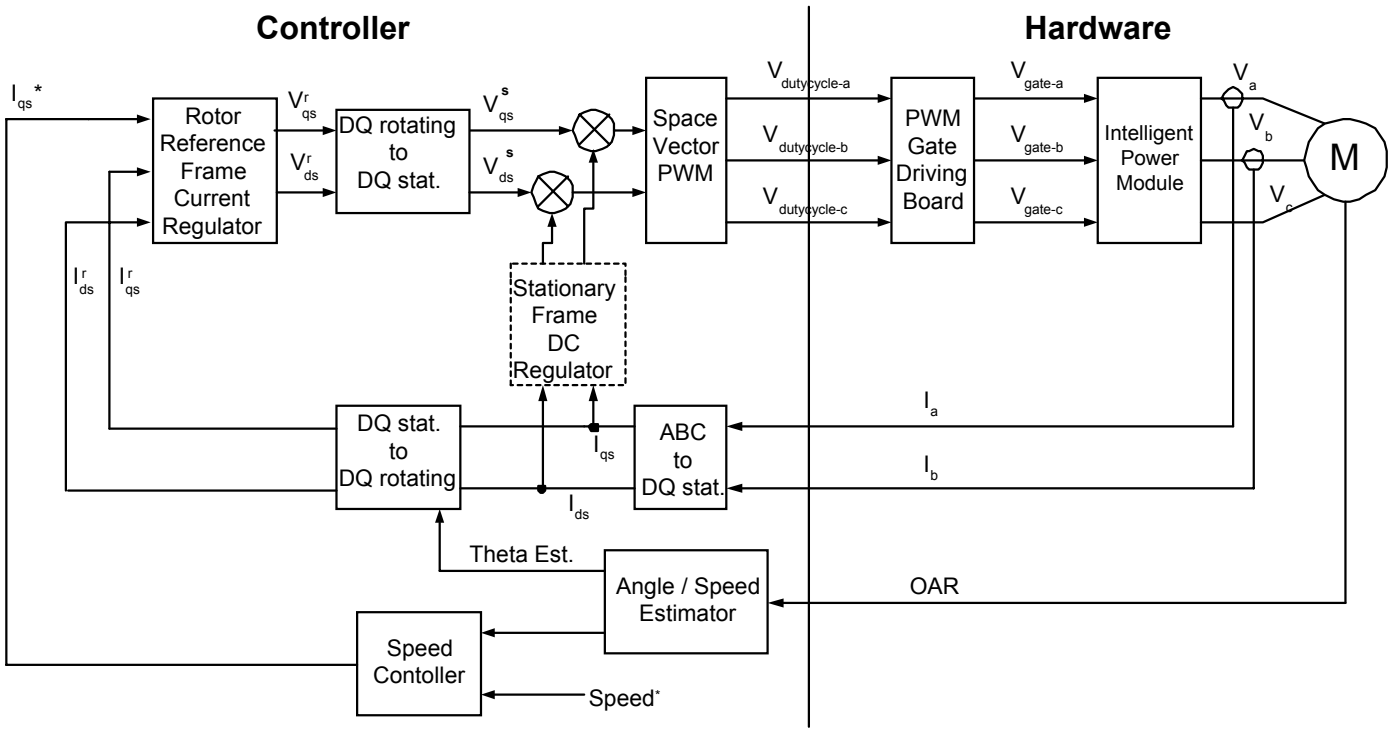
- Principle
  - Maintain stator current vector perpendicular to rotor magnetic field
  - Torque proportional to current magnitude
- Work completed with support of Penn State University

- Features Experimentally Demonstrated
  - Digital control of 4 pole permanent magnet motor
  - Space vector PWM to reduce bus voltage requirement
  - Angle / Speed estimate based on single step per revolution
  - Stationary frame regulator to eliminate DC component in motor current



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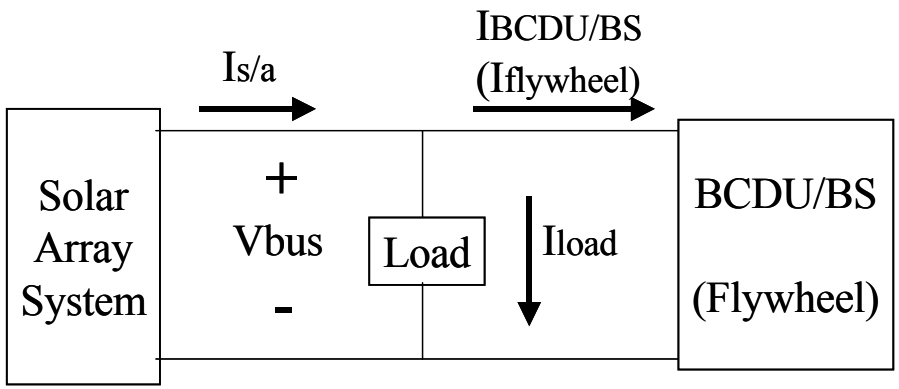
DC Bus Regulation

- Features Experimentally Demonstrated
  - DC bus regulation during changes in charge current set point and discharge load value was demonstrated.
  - Additionally mode transition algorithms were implemented and discussed.
  - Four types of regulation were compared: PI current, PI+Feedforward current, PI voltage, PI+Feedforward voltage
- Significance
  - This work shows that a flywheel energy storage system can mimic the operating modes of the ISS battery system.

Mode	BCDU/BS (Flywheel) DC Current	Regulated Bus Voltage
Charge	$I_{BCDU/BS} = I^*_{charge}$ $(I_{Flywheel} = I^*_{charge})$	$V_{bus} = V^*_{s/a}$
Discharge	$I_{BCDU/BS} < 0$ $(I_{Flywheel} < 0)$	$V_{bus} = V^*_{discharge}$
Charge Reduction	$I^*_{charge} > I_{BCDU/BS} > 0$ $(I^*_{charge} > I_{Flywheel} > 0)$	$V_{bus} = V^*_{discharge}$



Magnetic Bearing Sensor Upgrade

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- Features Experimentally Demonstrated
  - Differential eddy current sensors installed on all five position axis
  - PWM filters installed – all axes
  - Capacitive loading on radial sensors to reduce cross talk
- Benefits Compared to Unmodified Eddy Current Sensors
  - PWM filter reduces white noise from 1.0 mil to 0.16 mil (closed loop response)
  - Capacitive loading reduces crosstalk noise from 0.16 mil to 0.06 mil (closed loop response)
- Benefits Compared to Previous Sensors
  - Engine order noise eliminated
  - Overall noise level reduced from 3-6 mil runout down to 0.06 mil white noise
  - Control system complexity reduced
- Future Work
  - Common sensor drive circuit (custom or commercial)
  - Reduce noise at the source – MB PWM and MG inverter
- Work completed with support of TAMU

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Description of ACESE experiment

- A two degree of freedom energy and momentum control system will be experimentally demonstrated at NASA Glenn Research Center.
  - The system will consist of two flywheel modules operating on a low friction air table within a water blast containment facility for safety
  - The first two modules used in this demonstration will be upgraded versions of existing flywheel modules developed under previous Glenn flywheel programs. Each module will have permanent magnet motors and magnetic bearing systems
  - Research grade avionics utilizing COTS and custom built hardware will be used to drive the motor/generators and magnetic bearings
  - Control algorithms for system control, motor/generator control, and magnetic bearing control will be implemented and evaluated using the Simulink / Dspace rapid prototype environment

  - The following hardware is required for this experiment: D1 flywheel module, Upgraded High Speed Shaft, and the High Energy Flywheel Facility

ACESE System Diagram

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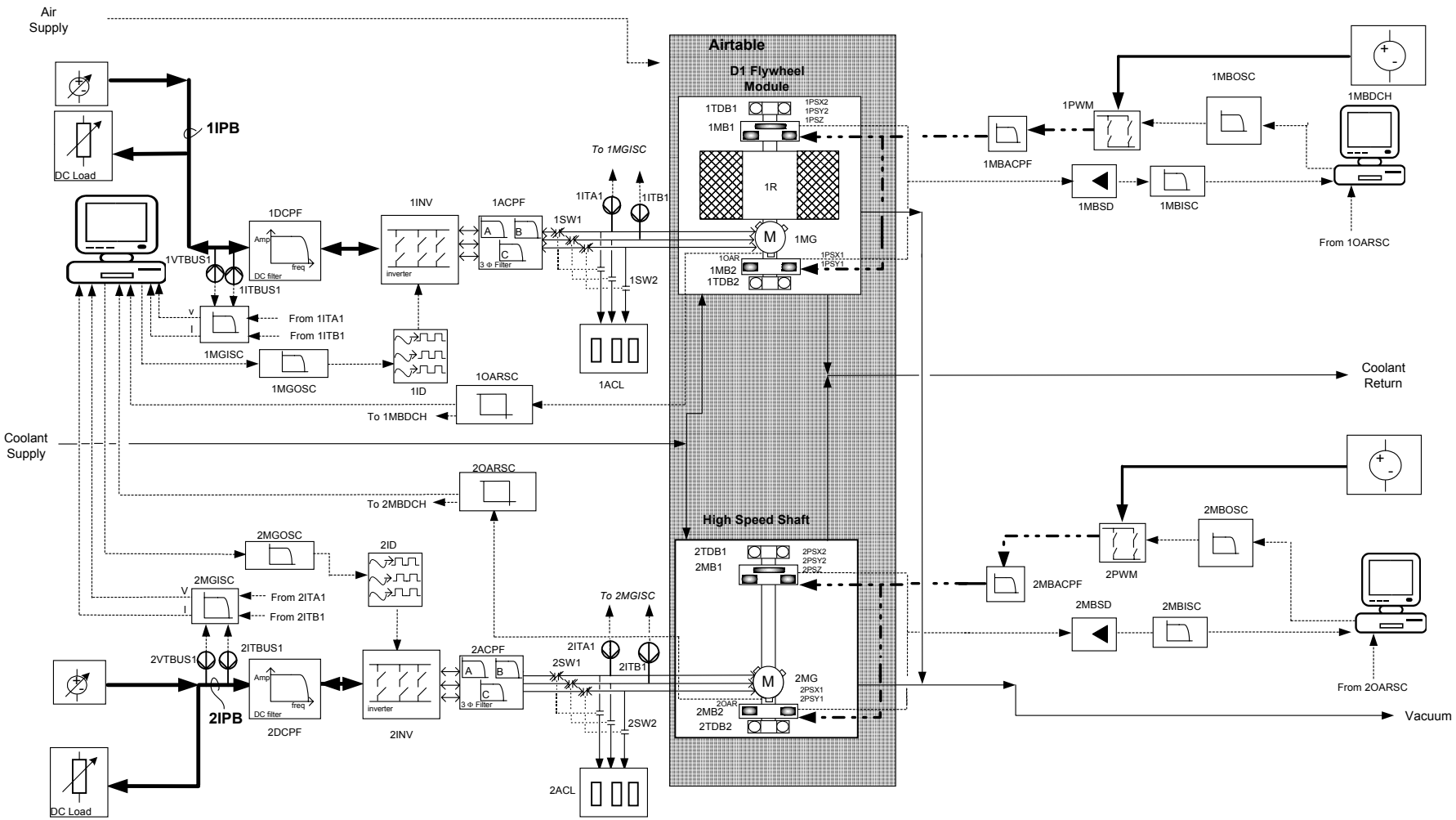

PRELIMINARY

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FY02 Objectives

- Demonstrate operation of two flywheel modules in HEFF
  - Bring HSS on line and demonstrate reliable operation to 60,000 RPM
  - Design D1 – Completed December 01
  - Build D1
  - Demonstrate reliable operation of D1
  - Install HSS, D1 in HEFF
  - Demonstrate operation
- Major technical milestones
  - GRC MB and MG control algorithms demonstrated to full speed
  - 2 Flywheel Module facility online

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Flywheel Module Upgrades

USFS High Speed Shaft

- T/D Bearings upgraded to Barden ZSB105 series, configuration is still cups at each end
  - COMPLETE
- Radial Reluctance sensor drive circuitry system built. Eddy current axial sensors and tachometer sensors replace optical
  - COMPLETE

D1 Module is complete redesign of USFS Dev 1 module.

- New rotor with Toray rim, monolithic steel design, redesigned magnetic bearing rotor path
- Magnetic bearing position sensors and motor tachometer sensors are eddy current
- T/D bearing configuration changed to shaft through design with single ended axial capture
- Motor/Generator changed to 2 pole – 80V line to line

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Flywheel Module Comparison

	HSS	D1
Quality	1st prototype	Upgrade
Manufacture	USFS	GRC
Rotor	None 30 W-Hr	4 Layer 300-Whr
M/G	3kW,300V	3kw,108V
MB	4 Pole PM	4 Pole PM
TD	2 cup	Cup/through
Housing	Vacuum	Vacuum

USFS – Development Unit 1

USFS – High Speed Shaft

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High Energy Flywheel Facility

Facility provides containment and infrastructure to conduct two flywheel module testing

- Features
  - Water based containment system
  - Air table for flywheel module mounting
  - DC power supplies
  - DC loads
  - AC loads
  - Vacuum system
  - Thermal control system
  - Data management systems
  - Alarms and shutdowns

High Energy Flywheel Facility (HEFF)

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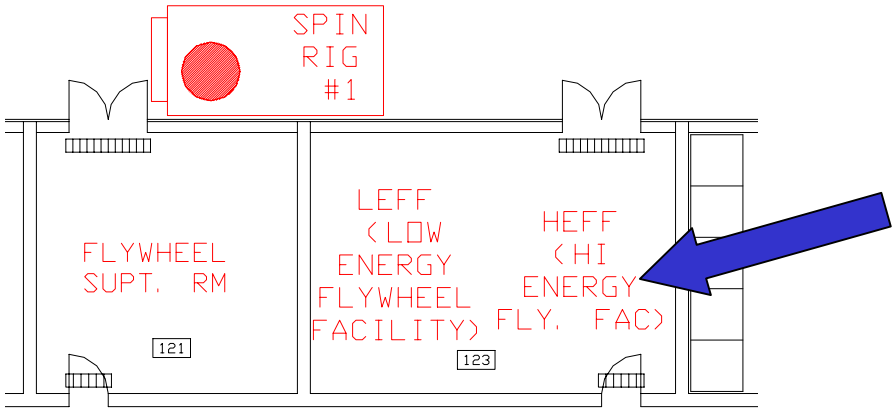

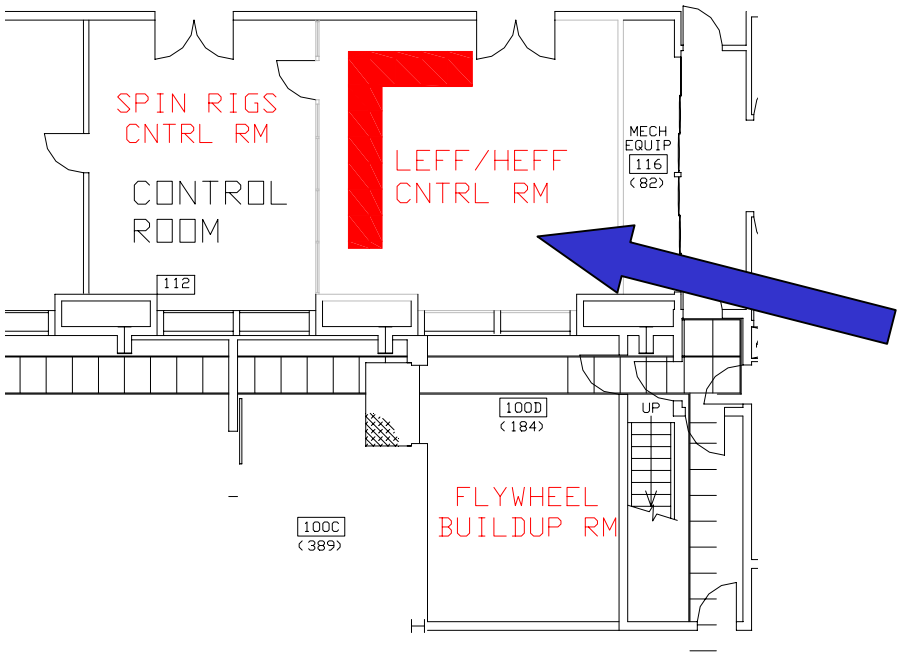

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Summary

- The ACESE experiment at NASA Glenn Research Center will demonstrate a system with DC bus regulation and single axis momentum control capability

- A facility for testing multiple flywheel modules at GRC will be completed by the end of this fiscal year